MULTIMEDIA UNIVERSITY

STUDENT ID NO

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# MULTIMEDIA UNIVERSITY

# FINAL EXAMINATION

**TRIMESTER 1, 2016/2017**

## ETN4086 – MOBILE AND SATELLITE COMMUNICATIONS

(TE, MCE)

12 OCTOBER 2016
2.30 p.m. – 4.30 p.m.
(2 Hours)

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**INSTRUCTION TO STUDENT**

1. This examination paper consists of **11 pages** (including the cover page) with 4 **questions only.**
2. Each question is worth **25 marks. Attempt ALL questions.**
3. Please write all your answers in the Answer Booklet provided. **Show all relevant steps** to obtain maximum marks.
4. There is an **appendix** of useful charts, constants and formulae at the end of this question paper.

## Question 1

(a) A handoff occurs when a mobile user leaves the coverage of one cell and moves into the coverage of the adjacent cell. Handoffs are categorised as soft and hard handoffs.

(i) Describe the difference between soft handoff and hard handoff.

[4 marks]

(ii) Briefly describe the effect of mobile user speed on handoff.

[2 marks]

(ii) With the aid of a sketch, describe an approach used to minimise the number of handoffs for mobile users in practical cellular systems.

[2 marks]

(b) Figure Q1.1 shows a cellular system using omni directional antenna. Co-channel cells ***Q*** are separated by a distance *D*. Each cell radius is 10km. The region has a path loss exponent, $n$=3. A Signal-to-Interference Ratio (SIR) of 18dB is required to meet the Quality of Service (QoS) for voice services in this system.

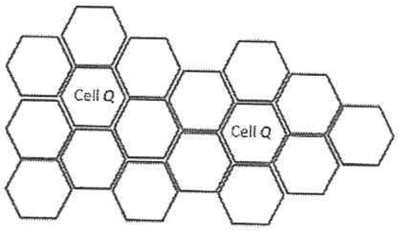


Figure Q1.1

(i) Determine if the required SIR=18dB is achieved by the system if only first-tier co-channel interference is considered.

[5 marks]

(ii) Design a new cellular system which can support the promised QoS using a suitable sectoring mechanism.

[6 marks]

(c) A cellular system using hexagonal cells, covers an area of 1560km$^2$ with a 12-cell reuse pattern. Each cell radius is 5km and cell area is approximated by $2.6R^2$ km$^2$. A total bandwidth of 25MHz is allocated to each cell of the cellular system. Each channel bandwidth is 200kHz. Each channel has 8 time slots and one time slot is allocated to one user. Each user uses an average of 0.05 Erlang with Grade of Service (GOS) of 2%. One control time slot is required per cell.

Calculate the number of subscribers that can be served by the cellular system.

[7 marks]

**Continued...**

## Question 2

(a)

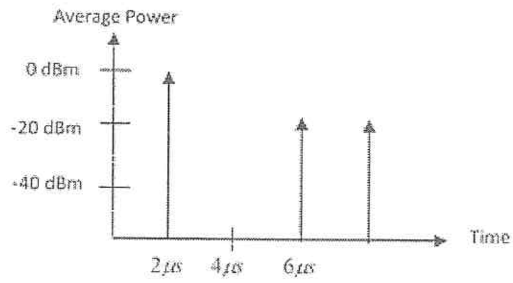


Figure Q2.1

Figure Q2.1 is the power delay profile of a type of channel fading.

(i) Identify the type of channel fading shown in the Figure Q2.1.

[1 mark]

(ii) Briefly describe the relationship between the coherence bandwidth and channel bandwidth for the type of fading in (a) (i).

[2 marks]

(b)

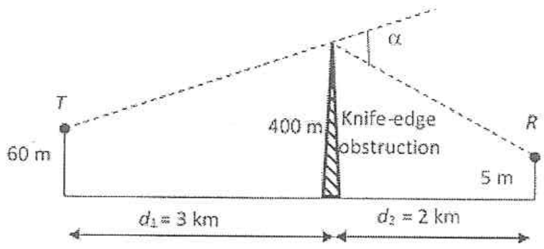


Figure Q2.2

A 900MHz carrier frequency is obstructed by a knife-edge obstruction shown in Figure Q2.2. Calculate the diffraction loss (in dB).

*Hint*: The Fresnel-Kirchoff diffraction parameter is given as $v = \alpha\sqrt{\dfrac{2d_1d_2}{\lambda(d_1+d_2)}}$

Diffraction gain, $G_d$ (dB), can be found using:

$$G_d(\text{dB}) = \begin{cases} 0, & v \le -1 \\ 20\log_{10}(0.5 - 0.62v), & -1 \le v \le 0 \\ 20\log_{10}(0.5\exp(-0.95v)), & 0 \le v \le 1 \\ 20\log_{10}\left(0.4 - \sqrt{0.1184 - (0.38 - 0.1v)^2}\right), & 1 \le v \le 2.4 \\ 20\log_{10}\left(\dfrac{0.225}{v}\right), & v > 2.4 \end{cases}$$

[10 marks]

**Continued...**

(c) The free space propagation model and two ray propagation model can be used to estimate path loss.

A system is transmitting at 10GHz. The received power at a reference distance $d_o$=1km is 1$\mu$W, and the height of the transmitting antenna ($h_t$) and receiving antenna ($h_r$) are 40m and 3m, respectively.

(i) Calculate the transmitted power at 1km.

[2 marks]

(ii) Calculate the received power and path loss (in dBm) at 10km using *both* the free space propagation model and the two ray propagation model.

[6 marks]

(iii) The field measured path loss at 10km from transmitter was found to be 120dB. Explain which model predicted the actual path loss more accurately and justify your answer.

[4 marks]

## Question 3

(a) With the aid of diagrams, describe the three Kepler's laws of planetary motion.

[9 marks]

(b) Satellite X in orbit has an inclination of 63.45° and circles the Earth once in 23h 56m 4s. Its apogee *altitude* is given as 39,105km and it is visible from the same location on Earth twice a day. The semi major axis for the orbit is given as $a$ = 26,561.734 km.

(i) Determine the type for Satellie X.

[1 mark]

(ii) Calculate the eccentricity $e$ and perigee *altitude*, $A_p$.

[4 marks]

(iii) Find the mean anomaly of the satellite after 2 minutes the passage of perigee.

[5 marks]

(c) Discuss how satellite orbital altitude affects the transmitter-receiver path loss and the life span of the satellite.

[6 marks]

**Continued...**

## Question 4

(a) Table Q4.1 shows data for a satellite link budget analysis. Calculate the following parameters based on this table.

Table Q4.1

| | |
|---|---|
| **Uplink** | |
| Frequency, $f_U$ | 14 GHz |
| Range | 42,000 km |
| $EIRP_U$ | 80 dBW |
| Clear sky atmospheric absorption | 0.3 dB |
| **Satellite transponder** | |
| Power flux density at saturation, $\phi_{sat}$ | -70 dBW/m$^2$ |
| Power flux density | -83.76dBW/m$^2$ |
| Directivity of receiving antenna, $G_{SRmax}$ | 45 dBi |
| Receiver feeder loss, $L_{FRX,S}$ | 3 dB |
| System noise temperature, $T$ | 600 K |
| EIRP at saturation, $EIRP_{sat}$ | 40 dBW |
| $A_{eff}$ | 1.16m$^2$ |
| Channel amplifier characteristic: | |
| OBO | -8.37dB |
| **Downlink** | |
| Frequency, $f_D$ | 12 GHz |
| Clear sky path loss | 200 dB |
| **Receiving earth station** | |
| Figure of Merit, $(G/T)_{ES}$ | 28 dB/K |
| Receiver feeder loss, $L_{FRX,ES}$ | 3dB |

(i) Satellite transponder input back-off, *IBO*.

[1 mark]

(ii) Saturated carrier power measured at the satellite receiver, $C_{U,sat}$

[3 marks]

(iii) Carrier power measured at the satellite receiver, $C_U$

[1 mark]

(iv) Uplink carrier-to-noise power spectral density, $(C/N_0)_U$

[3 marks]

(v) Downlink carrier-to-noise power spectral density, $(C/N_0)_D$

[2 marks]

(vi) Overall carrier-to-noise power spectral density, $(C/N_0)_T$

[2 marks]

**Continued...**

(b) A satellite located at 45°E, TASAEM-2, has a satellite transponder utilizing a 252-channel frequency division multiplexed voice system with the details shown in Table Q4.2.

Table Q4.2

| | |
|---|---|
| RMS deviation of 0 dBm test tone, $\Delta f_{rms}$ | 358 kHz |
| Multi-channel peak factor, $g$ | 3.2 |
| Maximum baseband frequency, $f_{max}$ | 1052 kHz |
| Guard band | 10% of the occupied bandwidth |
| Required Signal-to-Noise power ratio, $S/N$ | 60 dB |
| Pre-/de-emphasis gain, $P$ | 3.5 dB |
| Noise weighing factor, W | 3 dB |
| Voice channel | 4 kHz |

Calculate the:

(i) Required RF bandwidth.

[5 marks]

(ii) Carrier-to-noise power ratio, $C/N$.

[4 marks]

(c) State TWO subsystems on board the satellite and describe its functions.

[ 4 marks]

**Continued...**

## Appendix I: Constant values

| | | |
|---|---|---|
| Gravitation parameter, $\mu$ | = | $3.986 \times 10^{14}$ m$^3$/s$^2$ |
| Mean Earth radius, $R_E$ | = | 6378 km |
| Speed of light, $c$ | = | $3 \times 10^8$ m/s |
| Sidereal day | = | 23h 56m 4.09s |
| Boltzmann constant, $k$ | = | $1.379 \times 10^{-23}$ J/K = -228.6 dBW/Hz K |

## Appendix II: Table of Complementary Error Function

$$erfc(z) = \frac{2}{\sqrt{\pi}} \int_z^{\infty} e^{-t^2}\, dt \text{ for } 0 \le z \le 3.99 \text{ in steps of } 0.01$$

| z | 0.00 | 0.01 | 0.02 | 0.03 | 0.04 | 0.05 | 0.06 | 0.07 | 0.08 | 0.09 |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.0 | 1.000E+00 | 9.887E-01 | 9.774E-01 | 9.662E-01 | 9.549E-01 | 9.436E-01 | 9.324E-01 | 9.211E-01 | 9.099E-01 | 8.987E-01 |
| 0.1 | 8.875E-01 | 8.764E-01 | 8.652E-01 | 8.541E-01 | 8.431E-01 | 8.320E-01 | 8.210E-01 | 8.100E-01 | 7.991E-01 | 7.882E-01 |
| 0.2 | 7.773E-01 | 7.665E-01 | 7.557E-01 | 7.450E-01 | 7.343E-01 | 7.237E-01 | 7.131E-01 | 7.026E-01 | 6.921E-01 | 6.817E-01 |
| 0.3 | 6.714E-01 | 6.611E-01 | 6.509E-01 | 6.407E-01 | 6.306E-01 | 6.206E-01 | 6.107E-01 | 6.008E-01 | 5.910E-01 | 5.813E-01 |
| 0.4 | 5.716E-01 | 5.620E-01 | 5.525E-01 | 5.431E-01 | 5.338E-01 | 5.245E-01 | 5.153E-01 | 5.063E-01 | 4.973E-01 | 4.883E-01 |
| 0.5 | 4.795E-01 | 4.708E-01 | 4.621E-01 | 4.535E-01 | 4.451E-01 | 4.367E-01 | 4.284E-01 | 4.202E-01 | 4.121E-01 | 4.041E-01 |
| 0.6 | 3.961E-01 | 3.883E-01 | 3.806E-01 | 3.730E-01 | 3.654E-01 | 3.580E-01 | 3.506E-01 | 3.434E-01 | 3.362E-01 | 3.292E-01 |
| 0.7 | 3.222E-01 | 3.153E-01 | 3.086E-01 | 3.019E-01 | 2.953E-01 | 2.888E-01 | 2.825E-01 | 2.762E-01 | 2.700E-01 | 2.639E-01 |
| 0.8 | 2.579E-01 | 2.520E-01 | 2.462E-01 | 2.405E-01 | 2.349E-01 | 2.293E-01 | 2.239E-01 | 2.186E-01 | 2.133E-01 | 2.082E-01 |
| 0.9 | 2.031E-01 | 1.981E-01 | 1.932E-01 | 1.884E-01 | 1.837E-01 | 1.791E-01 | 1.746E-01 | 1.701E-01 | 1.658E-01 | 1.615E-01 |
| 1.0 | 1.573E-01 | 1.532E-01 | 1.492E-01 | 1.452E-01 | 1.414E-01 | 1.376E-01 | 1.339E-01 | 1.302E-01 | 1.267E-01 | 1.232E-01 |
| 1.1 | 1.198E-01 | 1.165E-01 | 1.132E-01 | 1.100E-01 | 1.069E-01 | 1.039E-01 | 1.009E-01 | 9.800E-02 | 9.516E-02 | 9.239E-02 |
| 1.2 | 8.969E-02 | 8.704E-02 | 8.447E-02 | 8.195E-02 | 7.949E-02 | 7.710E-02 | 7.476E-02 | 7.249E-02 | 7.027E-02 | 6.810E-02 |
| 1.3 | 6.599E-02 | 6.394E-02 | 6.193E-02 | 5.998E-02 | 5.809E-02 | 5.624E-02 | 5.444E-02 | 5.269E-02 | 5.098E-02 | 4.933E-02 |
| 1.4 | 4.771E-02 | 4.615E-02 | 4.462E-02 | 4.314E-02 | 4.170E-02 | 4.030E-02 | 3.895E-02 | 3.763E-02 | 3.635E-02 | 3.510E-02 |
| 1.5 | 3.389E-02 | 3.272E-02 | 3.159E-02 | 3.048E-02 | 2.941E-02 | 2.838E-02 | 2.737E-02 | 2.640E-02 | 2.545E-02 | 2.454E-02 |
| 1.6 | 2.365E-02 | 2.279E-02 | 2.196E-02 | 2.116E-02 | 2.038E-02 | 1.962E-02 | 1.890E-02 | 1.819E-02 | 1.751E-02 | 1.685E-02 |
| 1.7 | 1.621E-02 | 1.559E-02 | 1.500E-02 | 1.442E-02 | 1.387E-02 | 1.333E-02 | 1.281E-02 | 1.231E-02 | 1.183E-02 | 1.136E-02 |
| 1.8 | 1.091E-02 | 1.048E-02 | 1.006E-02 | 9.653E-03 | 9.264E-03 | 8.889E-03 | 8.528E-03 | 8.179E-03 | 7.844E-03 | 7.521E-03 |
| 1.9 | 7.210E-03 | 6.910E-03 | 6.622E-03 | 6.344E-03 | 6.077E-03 | 5.821E-03 | 5.574E-03 | 5.336E-03 | 5.108E-03 | 4.889E-03 |
| 2.0 | 4.678E-03 | 4.475E-03 | 4.281E-03 | 4.094E-03 | 3.914E-03 | 3.742E-03 | 3.577E-03 | 3.418E-03 | 3.266E-03 | 3.120E-03 |
| 2.1 | 2.979E-03 | 2.845E-03 | 2.716E-03 | 2.593E-03 | 2.475E-03 | 2.361E-03 | 2.253E-03 | 2.149E-03 | 2.049E-03 | 1.954E-03 |
| 2.2 | 1.863E-03 | 1.776E-03 | 1.692E-03 | 1.612E-03 | 1.536E-03 | 1.463E-03 | 1.393E-03 | 1.326E-03 | 1.262E-03 | 1.201E-03 |
| 2.3 | 1.143E-03 | 1.088E-03 | 1.034E-03 | 9.838E-04 | 9.354E-04 | 8.893E-04 | 8.452E-04 | 8.032E-04 | 7.631E-04 | 7.249E-04 |
| 2.4 | 6.885E-04 | 6.538E-04 | 6.207E-04 | 5.892E-04 | 5.592E-04 | 5.306E-04 | 5.034E-04 | 4.774E-04 | 4.528E-04 | 4.293E-04 |
| 2.5 | 4.070E-04 | 3.857E-04 | 3.655E-04 | 3.463E-04 | 3.280E-04 | 3.107E-04 | 2.942E-04 | 2.785E-04 | 2.636E-04 | 2.495E-04 |
| 2.6 | 2.360E-04 | 2.233E-04 | 2.112E-04 | 1.997E-04 | 1.888E-04 | 1.785E-04 | 1.687E-04 | 1.594E-04 | 1.506E-04 | 1.422E-04 |
| 2.7 | 1.343E-04 | 1.268E-04 | 1.197E-04 | 1.130E-04 | 1.066E-04 | 1.006E-04 | 9.492E-05 | 8.952E-05 | 8.441E-05 | 7.958E-05 |
| 2.8 | 7.501E-05 | 7.069E-05 | 6.661E-05 | 6.275E-05 | 5.910E-05 | 5.566E-05 | 5.240E-05 | 4.933E-05 | 4.642E-05 | 4.368E-05 |
| 2.9 | 4.110E-05 | 3.866E-05 | 3.635E-05 | 3.418E-05 | 3.213E-05 | 3.020E-05 | 2.838E-05 | 2.667E-05 | 2.505E-05 | 2.353E-05 |
| 3.0 | 2.209E-05 | 2.074E-05 | 1.947E-05 | 1.827E-05 | 1.714E-05 | 1.608E-05 | 1.508E-05 | 1.414E-05 | 1.326E-05 | 1.243E-05 |
| 3.1 | 1.165E-05 | 1.092E-05 | 1.023E-05 | 9.578E-06 | 8.970E-06 | 8.398E-06 | 7.862E-06 | 7.358E-06 | 6.885E-06 | 6.442E-06 |
| 3.2 | 6.026E-06 | 5.635E-06 | 5.269E-06 | 4.926E-06 | 4.604E-06 | 4.303E-06 | 4.020E-06 | 3.755E-06 | 3.507E-06 | 3.275E-06 |
| 3.3 | 3.058E-06 | 2.854E-06 | 2.664E-06 | 2.485E-06 | 2.319E-06 | 2.162E-06 | 2.017E-06 | 1.880E-06 | 1.753E-06 | 1.633E-06 |
| 3.4 | 1.522E-06 | 1.418E-06 | 1.321E-06 | 1.230E-06 | 1.145E-06 | 1.066E-06 | 9.922E-07 | 9.233E-07 | 8.590E-07 | 7.990E-07 |
| 3.5 | 7.431E-07 | 6.910E-07 | 6.423E-07 | 5.970E-07 | 5.548E-07 | 5.155E-07 | 4.788E-07 | 4.447E-07 | 4.130E-07 | 3.834E-07 |
| 3.6 | 3.559E-07 | 3.303E-07 | 3.064E-07 | 2.843E-07 | 2.636E-07 | 2.445E-07 | 2.267E-07 | 2.101E-07 | 1.947E-07 | 1.804E-07 |
| 3.7 | 1.672E-07 | 1.548E-07 | 1.434E-07 | 1.327E-07 | 1.229E-07 | 1.137E-07 | 1.052E-07 | 9.736E-08 | 9.005E-08 | 8.328E-08 |
| 3.8 | 7.700E-08 | 7.119E-08 | 6.579E-08 | 6.080E-08 | 5.617E-08 | 5.189E-08 | 4.792E-08 | 4.425E-08 | 4.085E-08 | 3.770E-08 |
| 3.9 | 3.479E-08 | 3.210E-08 | 2.961E-08 | 2.731E-08 | 2.518E-08 | 2.322E-08 | 2.140E-08 | 1.972E-08 | 1.817E-08 | 1.674E-08 |

Note: 1.000E-01 = $1.000 \times 10^{-1}$

For $z > 4$, $\quad erfc(z) \approx \frac{1}{\sqrt{\pi}}\left(\frac{e^{-z^2}}{z}\right)$

**Continued...**

## Appendix III: Erlang B and Erlang C Chart

### Erlang B Traffic Table

Maximum Offered Load Versus B and N
B is in %

| N/B | 0.01 | 0.05 | 0.1 | 0.5 | 1.0 | 2 | 5 | 10 | 15 | 20 | 30 | 40 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | .0001 | .0005 | .0010 | .0050 | .0101 | .0204 | .0526 | .1111 | .1765 | .2500 | .4286 | .6667 |
| 2 | .0142 | .0321 | .0458 | .1054 | .1526 | .2235 | .3813 | .5954 | .7962 | 1.000 | 1.449 | 2.000 |
| 3 | .0868 | .1517 | .1938 | .3490 | .4555 | .6022 | .8994 | 1.271 | 1.603 | 1.930 | 2.633 | 3.480 |
| 4 | .2347 | .3624 | .4393 | .7012 | .8694 | 1.092 | 1.525 | 2.045 | 2.501 | 2.945 | 3.891 | 5.021 |
| 5 | .4520 | .6486 | .7621 | 1.132 | 1.361 | 1.657 | 2.219 | 2.881 | 3.454 | 4.010 | 5.189 | 6.596 |
| 6 | .7282 | .9957 | 1.146 | 1.622 | 1.909 | 2.276 | 2.960 | 3.758 | 4.445 | 5.109 | 6.514 | 8.191 |
| 7 | 1.054 | 1.392 | 1.579 | 2.158 | 2.501 | 2.935 | 3.738 | 4.666 | 5.461 | 6.230 | 7.856 | 9.800 |
| 8 | 1.422 | 1.830 | 2.051 | 2.730 | 3.128 | 3.627 | 4.543 | 5.597 | 6.498 | 7.369 | 9.213 | 11.42 |
| 9 | 1.826 | 2.302 | 2.558 | 3.333 | 3.783 | 4.345 | 5.370 | 6.546 | 7.551 | 8.522 | 10.58 | 13.05 |
| 10 | 2.260 | 2.803 | 3.092 | 3.961 | 4.461 | 5.084 | 6.216 | 7.511 | 8.616 | 9.685 | 11.95 | 14.68 |
| 11 | 2.722 | 3.329 | 3.651 | 4.610 | 5.160 | 5.842 | 7.076 | 8.487 | 9.691 | 10.86 | 13.33 | 16.31 |
| 12 | 3.207 | 3.878 | 4.231 | 5.279 | 5.876 | 6.615 | 7.950 | 9.474 | 10.78 | 12.04 | 14.72 | 17.95 |
| 13 | 3.713 | 4.447 | 4.831 | 5.964 | 6.607 | 7.402 | 8.835 | 10.47 | 11.87 | 13.22 | 16.11 | 19.60 |
| 14 | 4.239 | 5.032 | 5.446 | 6.663 | 7.352 | 8.200 | 9.730 | 11.47 | 12.97 | 14.41 | 17.50 | 21.24 |
| 15 | 4.781 | 5.634 | 6.077 | 7.376 | 8.108 | 9.010 | 10.63 | 12.48 | 14.07 | 15.61 | 18.90 | 22.89 |
| 16 | 5.339 | 6.250 | 6.722 | 8.100 | 8.875 | 9.828 | 11.54 | 13.50 | 15.18 | 16.81 | 20.30 | 24.54 |
| 17 | 5.911 | 6.878 | 7.378 | 8.834 | 9.652 | 10.66 | 12.46 | 14.52 | 16.29 | 18.01 | 21.70 | 26.19 |
| 18 | 6.496 | 7.519 | 8.046 | 9.578 | 10.44 | 11.49 | 13.39 | 15.55 | 17.41 | 19.22 | 23.10 | 27.84 |
| 19 | 7.093 | 8.170 | 8.724 | 10.33 | 11.23 | 12.33 | 14.32 | 16.58 | 18.53 | 20.42 | 24.51 | 29.50 |
| 20 | 7.701 | 8.831 | 9.412 | 11.09 | 12.03 | 13.18 | 15.25 | 17.61 | 19.65 | 21.64 | 25.92 | 31.15 |
| 21 | 8.319 | 9.501 | 10.11 | 11.86 | 12.84 | 14.04 | 16.19 | 18.65 | 20.77 | 22.85 | 27.33 | 32.81 |
| 22 | 8.946 | 10.18 | 10.81 | 12.64 | 13.65 | 14.90 | 17.13 | 19.69 | 21.90 | 24.06 | 28.74 | 34.46 |
| 23 | 9.583 | 10.87 | 11.52 | 13.42 | 14.47 | 15.76 | 18.08 | 20.74 | 23.03 | 25.28 | 30.15 | 36.12 |
| 24 | 10.23 | 11.56 | 12.24 | 14.20 | 15.30 | 16.63 | 19.03 | 21.78 | 24.16 | 26.50 | 31.56 | 37.78 |
| 25 | 10.88 | 12.26 | 12.97 | 15.00 | 16.13 | 17.51 | 19.99 | 22.83 | 25.30 | 27.72 | 32.97 | 39.44 |
| 26 | 11.54 | 12.97 | 13.70 | 15.80 | 16.96 | 18.38 | 20.94 | 23.89 | 26.43 | 28.94 | 34.39 | 41.10 |
| 27 | 12.21 | 13.69 | 14.44 | 16.60 | 17.80 | 19.27 | 21.90 | 24.94 | 27.57 | 30.16 | 35.80 | 42.76 |
| 28 | 12.88 | 14.41 | 15.18 | 17.41 | 18.64 | 20.15 | 22.87 | 26.00 | 28.71 | 31.39 | 37.21 | 44.41 |
| 29 | 13.56 | 15.13 | 15.93 | 18.22 | 19.49 | 21.04 | 23.83 | 27.05 | 29.85 | 32.61 | 38.63 | 46.07 |
| 30 | 14.25 | 15.86 | 16.68 | 19.03 | 20.34 | 21.93 | 24.80 | 28.11 | 31.00 | 33.84 | 40.05 | 47.74 |
| 31 | 14.94 | 16.60 | 17.44 | 19.85 | 21.19 | 22.83 | 25.77 | 29.17 | 32.14 | 35.07 | 41.46 | 49.40 |
| 32 | 15.63 | 17.34 | 18.21 | 20.68 | 22.05 | 23.73 | 26.75 | 30.24 | 33.28 | 36.30 | 42.88 | 51.06 |
| 33 | 16.34 | 18.09 | 18.97 | 21.51 | 22.91 | 24.63 | 27.72 | 31.30 | 34.43 | 37.52 | 44.30 | 52.72 |
| 34 | 17.04 | 18.84 | 19.74 | 22.34 | 23.77 | 25.53 | 28.70 | 32.37 | 35.58 | 38.75 | 45.72 | 54.38 |
| 35 | 17.75 | 19.59 | 20.52 | 23.17 | 24.64 | 26.44 | 29.68 | 33.43 | 36.72 | 39.99 | 47.14 | 56.04 |
| 36 | 18.47 | 20.35 | 21.30 | 24.01 | 25.51 | 27.34 | 30.66 | 34.50 | 37.87 | 41.22 | 48.56 | 57.70 |
| 37 | 19.19 | 21.11 | 22.08 | 24.85 | 26.38 | 28.25 | 31.64 | 35.57 | 39.02 | 42.45 | 49.98 | 59.37 |
| 38 | 19.91 | 21.87 | 22.86 | 25.69 | 27.25 | 29.17 | 32.62 | 36.64 | 40.17 | 43.68 | 51.40 | 61.03 |
| 39 | 20.64 | 22.64 | 23.65 | 26.53 | 28.13 | 30.08 | 33.61 | 37.72 | 41.32 | 44.91 | 52.82 | 62.69 |
| 40 | 21.37 | 23.41 | 24.44 | 27.38 | 29.01 | 31.00 | 34.60 | 38.79 | 42.48 | 46.15 | 54.24 | 64.35 |
| 41 | 22.11 | 24.19 | 25.24 | 28.23 | 29.89 | 31.92 | 35.58 | 39.86 | 43.63 | 47.38 | 55.66 | 66.02 |
| 42 | 22.85 | 24.97 | 26.04 | 29.09 | 30.77 | 32.84 | 36.57 | 40.94 | 44.78 | 48.62 | 57.08 | 67.68 |
| 43 | 23.59 | 25.75 | 26.84 | 29.94 | 31.66 | 33.76 | 37.57 | 42.01 | 45.94 | 49.85 | 58.50 | 69.34 |
| 44 | 24.33 | 26.53 | 27.64 | 30.80 | 32.54 | 34.68 | 38.56 | 43.09 | 47.09 | 51.09 | 59.92 | 71.01 |
| 45 | 25.08 | 27.32 | 28.45 | 31.66 | 33.43 | 35.61 | 39.55 | 44.17 | 48.25 | 52.32 | 61.35 | 72.67 |

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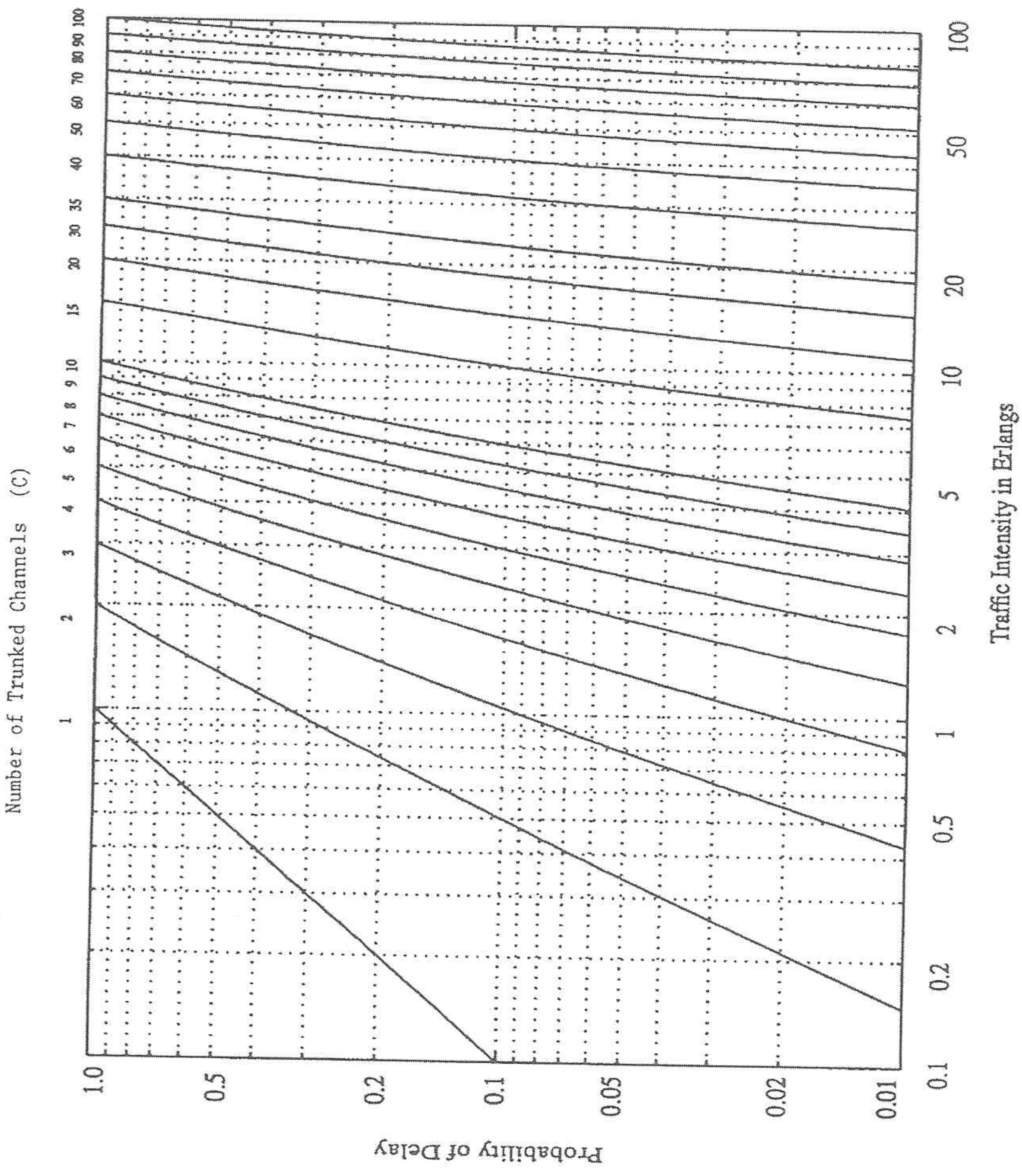
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 46 | 25.83 | 28.11 | 29.26 | 32.52 | 34.32 | 36.53 | 40.55 | 45.24 | 49.40 | 53.56 | 62.77 | 74.33 |
| 47 | 26.59 | 28.90 | 30.07 | 33.38 | 35.22 | 37.46 | 41.54 | 46.32 | 50.56 | 54.80 | 64.19 | 76.00 |
| 48 | 27.34 | 29.70 | 30.88 | 34.25 | 36.11 | 38.39 | 42.54 | 47.40 | 51.71 | 56.03 | 65.61 | 77.66 |
| 49 | 28.10 | 30.49 | 31.69 | 35.11 | 37.00 | 39.32 | 43.53 | 48.48 | 52.87 | 57.27 | 67.04 | 79.32 |
| 50 | 28.87 | 31.29 | 32.51 | 35.98 | 37.90 | 40.26 | 44.53 | 49.56 | 54.03 | 58.51 | 68.46 | 80.99 |
| 51 | 29.63 | 32.09 | 33.33 | 36.85 | 38.80 | 41.19 | 45.53 | 50.64 | 55.19 | 59.75 | 69.88 | 82.65 |
| 52 | 30.40 | 32.90 | 34.15 | 37.72 | 39.70 | 42.12 | 46.53 | 51.73 | 56.35 | 60.99 | 71.31 | 84.32 |
| 53 | 31.17 | 33.70 | 34.98 | 38.60 | 40.60 | 43.06 | 47.53 | 52.81 | 57.50 | 62.22 | 72.73 | 85.98 |
| 54 | 31.94 | 34.51 | 35.80 | 39.47 | 41.51 | 44.00 | 48.54 | 53.89 | 58.66 | 63.46 | 74.15 | 87.65 |
| 55 | 32.72 | 35.32 | 36.63 | 40.35 | 42.41 | 44.94 | 49.54 | 54.98 | 59.82 | 64.70 | 75.58 | 89.31 |
| 56 | 33.49 | 36.13 | 37.46 | 41.23 | 43.32 | 45.88 | 50.54 | 56.06 | 60.98 | 65.94 | 77.00 | 90.97 |
| 57 | 34.27 | 36.95 | 38.29 | 42.11 | 44.22 | 46.82 | 51.55 | 57.14 | 62.14 | 67.18 | 78.43 | 92.64 |
| 58 | 35.05 | 37.76 | 39.12 | 42.99 | 45.13 | 47.76 | 52.55 | 58.23 | 63.31 | 68.42 | 79.85 | 94.30 |
| 59 | 35.84 | 38.58 | 39.96 | 43.87 | 46.04 | 48.70 | 53.56 | 59.32 | 64.47 | 69.66 | 81.27 | 95.97 |
| 60 | 36.62 | 39.40 | 40.80 | 44.76 | 46.95 | 49.64 | 54.57 | 60.40 | 65.63 | 70.90 | 82.70 | 97.63 |
| 61 | 37.41 | 40.22 | 41.63 | 45.64 | 47.86 | 50.59 | 55.57 | 61.49 | 66.79 | 72.14 | 84.12 | 99.30 |
| 62 | 38.20 | 41.05 | 42.47 | 46.53 | 48.77 | 51.53 | 56.58 | 62.58 | 67.95 | 73.38 | 85.55 | 101.0 |
| 63 | 38.99 | 41.87 | 43.31 | 47.42 | 49.69 | 52.48 | 57.59 | 63.66 | 69.11 | 74.63 | 86.97 | 102.6 |
| 64 | 39.78 | 42.70 | 44.16 | 48.31 | 50.60 | 53.43 | 58.60 | 64.75 | 70.28 | 75.87 | 88.40 | 104.3 |
| 65 | 40.58 | 43.52 | 45.00 | 49.20 | 51.52 | 54.38 | 59.61 | 65.84 | 71.44 | 77.11 | 89.82 | 106.0 |
| 66 | 41.38 | 44.35 | 45.85 | 50.09 | 52.44 | 55.33 | 60.62 | 66.93 | 72.60 | 78.35 | 91.25 | 107.6 |
| 67 | 42.17 | 45.18 | 46.69 | 50.98 | 53.35 | 56.28 | 61.63 | 68.02 | 73.77 | 79.59 | 92.67 | 109.3 |
| 68 | 42.97 | 46.02 | 47.54 | 51.87 | 54.27 | 57.23 | 62.64 | 69.11 | 74.93 | 80.83 | 94.10 | 111.0 |
| 69 | 43.77 | 46.85 | 48.39 | 52.77 | 55.19 | 58.18 | 63.65 | 70.20 | 76.09 | 82.08 | 95.52 | 112.6 |
| 70 | 44.58 | 47.68 | 49.24 | 53.66 | 56.11 | 59.13 | 64.67 | 71.29 | 77.26 | 83.32 | 96.95 | 114.3 |
| 71 | 45.38 | 48.52 | 50.09 | 54.56 | 57.03 | 60.08 | 65.68 | 72.38 | 78.42 | 84.56 | 98.37 | 116.0 |
| 72 | 46.19 | 49.36 | 50.94 | 55.46 | 57.96 | 61.04 | 66.69 | 73.47 | 79.59 | 85.80 | 99.80 | 117.6 |
| 73 | 47.00 | 50.20 | 51.80 | 56.35 | 58.88 | 61.99 | 67.71 | 74.56 | 80.75 | 87.05 | 101.2 | 119.3 |
| 74 | 47.81 | 51.04 | 52.65 | 57.25 | 59.80 | 62.95 | 68.72 | 75.65 | 81.92 | 88.29 | 102.7 | 120.9 |
| 75 | 48.62 | 51.88 | 53.51 | 58.15 | 60.73 | 63.90 | 69.74 | 76.74 | 83.08 | 89.53 | 104.1 | 122.6 |
| 76 | 49.43 | 52.72 | 54.37 | 59.05 | 61.65 | 64.86 | 70.75 | 77.83 | 84.25 | 90.78 | 105.5 | 124.3 |
| 77 | 50.24 | 53.56 | 55.23 | 59.96 | 62.58 | 65.81 | 71.77 | 78.93 | 85.41 | 92.02 | 106.9 | 125.9 |
| 78 | 51.05 | 54.41 | 56.09 | 60.86 | 63.51 | 66.77 | 72.79 | 80.02 | 86.58 | 93.26 | 108.4 | 127.6 |
| 79 | 51.87 | 55.25 | 56.95 | 61.76 | 64.43 | 67.73 | 73.80 | 81.11 | 87.74 | 94.51 | 109.8 | 129.3 |
| 80 | 52.69 | 56.10 | 57.81 | 62.67 | 65.36 | 68.69 | 74.82 | 82.20 | 88.91 | 95.75 | 111.2 | 130.9 |
| 81 | 53.51 | 56.95 | 58.67 | 63.57 | 66.29 | 69.65 | 75.84 | 83.30 | 90.08 | 96.99 | 112.6 | 132.6 |
| 82 | 54.33 | 57.80 | 59.54 | 64.48 | 67.22 | 70.61 | 76.86 | 84.39 | 91.24 | 98.24 | 114.1 | 134.3 |
| 83 | 55.15 | 58.65 | 60.40 | 65.39 | 68.15 | 71.57 | 77.87 | 85.48 | 92.41 | 99.48 | 115.5 | 135.9 |
| 84 | 55.97 | 59.50 | 61.27 | 66.29 | 69.08 | 72.53 | 78.89 | 86.58 | 93.58 | 100.7 | 116.9 | 137.6 |
| 85 | 56.79 | 60.35 | 62.14 | 67.20 | 70.02 | 73.49 | 79.91 | 87.67 | 94.74 | 102.0 | 118.3 | 139.3 |
| 86 | 57.62 | 61.21 | 63.00 | 68.11 | 70.95 | 74.45 | 80.93 | 88.77 | 95.91 | 103.2 | 119.8 | 140.9 |
| 87 | 58.44 | 62.06 | 63.87 | 69.02 | 71.88 | 75.42 | 81.95 | 89.86 | 97.08 | 104.5 | 121.2 | 142.6 |
| 88 | 59.27 | 62.92 | 64.74 | 69.93 | 72.82 | 76.38 | 82.97 | 90.96 | 98.25 | 105.7 | 122.6 | 144.3 |
| 89 | 60.10 | 63.77 | 65.61 | 70.84 | 73.75 | 77.34 | 83.99 | 92.05 | 99.41 | 107.0 | 124.0 | 145.9 |
| 90 | 60.92 | 64.63 | 66.48 | 71.76 | 74.68 | 78.31 | 85.01 | 93.15 | 100.6 | 108.2 | 125.5 | 147.6 |
| 91 | 61.75 | 65.49 | 67.36 | 72.67 | 75.62 | 79.27 | 86.04 | 94.24 | 101.8 | 109.4 | 126.9 | 149.3 |
| 92 | 62.58 | 66.35 | 68.23 | 73.58 | 76.56 | 80.24 | 87.06 | 95.34 | 102.9 | 110.7 | 128.3 | 150.9 |
| 93 | 63.42 | 67.21 | 69.10 | 74.50 | 77.49 | 81.20 | 88.08 | 96.43 | 104.1 | 111.9 | 129.8 | 152.6 |
| 94 | 64.25 | 68.07 | 69.98 | 75.41 | 78.43 | 82.17 | 89.10 | 97.53 | 105.3 | 113.2 | 131.2 | 154.3 |
| 95 | 65.08 | 68.93 | 70.85 | 76.33 | 79.37 | 83.13 | 90.12 | 98.63 | 106.4 | 114.4 | 132.6 | 155.9 |
| 96 | 65.92 | 69.79 | 71.73 | 77.24 | 80.31 | 84.10 | 91.15 | 99.72 | 107.6 | 115.7 | 134.0 | 157.6 |
| 97 | 66.75 | 70.65 | 72.61 | 78.16 | 81.25 | 85.07 | 92.17 | 100.8 | 108.8 | 116.9 | 135.5 | 159.3 |
| 98 | 67.59 | 71.52 | 73.48 | 79.07 | 82.18 | 86.04 | 93.19 | 101.9 | 109.9 | 118.2 | 136.9 | 160.9 |
| 99 | 68.43 | 72.38 | 74.36 | 79.99 | 83.12 | 87.00 | 94.22 | 103.0 | 111.1 | 119.4 | 138.3 | 162.6 |
| 100 | 69.27 | 7~.25 | 75.24 | 80.91 | 84.06 | 87.97 | 95.24 | 104.1 | 112.3 | 120.6 | 139.7 | 164.3 |

N is the number of servers. The numerical column headings indicate blocking probability B in %. Table generated by Dan Dexter

Continued...




The Erlang C chart showing the probability of a call being delayed as a function of the number of channels and traffic intensity in Erlangs.

Continued...

**Antenna**

Effective isotropic radiated power, $EIRP = P_t G_t$

Power flux density, $\phi = \dfrac{EIRP}{4\pi R^2}$

Received power, $P_r = \phi A_{eff}$

Antenna gain of a circular aperture or reflector of diameter $D$:

$$G_{\max} = \left(\frac{4\pi}{\lambda^2}\right)A_{eff} = \eta\left(\frac{\pi D}{\lambda}\right)^2 = \eta\left(\frac{70\pi}{\theta_{3dB}}\right)^2, \text{ where } \theta_{3dB} = 70\left(\frac{\lambda}{D}\right)$$

**Link Analysis**

Received power, $[P_r] = [EIRP] + [G_r] - [L_{Total}]$

Free space loss,

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L}$$

$$PL(\text{dB}) = 10\log\left(\frac{P_t}{P_r}\right) = -10\log\left(\frac{\lambda^2}{(4\pi)^2 d^2}\right)$$

$$P_r(d)\,\text{dBm} = 10\log\left[\frac{P_r(d_0)}{0.001\text{ W}}\right] + 20\log\left(\frac{d_0}{d}\right) \qquad d \ge d_0 \ge d_f$$

Log-Distance Path Loss

$$\overline{PL}(\text{dB}) = \overline{PL}(d_0) + 10\,n\log\left(\frac{d}{d_0}\right)$$

Doppler shift,

$$f_d = \frac{v}{\lambda}\cos\theta$$

Noise power spectral density, $N_o = kT$

Noise factor, $F = 1 + \dfrac{T_e}{T_o}$

System noise temperature with reference to the antenna output,

$$T_S = T_{ant} + T_{e1} + \frac{T_{e2}}{G_1} + \frac{T_{e3}}{G_1 G_2} + \ldots + \frac{T_{en}}{G_1 G_2 \ldots G_{n-1}}$$

**FDM-FM-FDMA Satellite System**

Signal bandwidth, $B = 2(gl\Delta f_{rms} + f_{max})$

$$\text{where } \log_{10} l = \begin{cases} (-1 + 4\log_{10} n)/20, & n \le 240 \\ (-15 + 10\log_{10} n)/20, & n > 240 \end{cases}$$

Relationship between $C/N$ and $S/N$ is given by:

$$\frac{C}{N} = \left(\frac{S}{N}\right)\left(\frac{b}{B}\right)\left(\frac{f_{\max}}{\Delta f_{rms}}\right)^2 \frac{1}{pw}$$

**End of Paper**